Research Article

Adaptive Modulation based MIMO-OFDM Receiver design for Underwater Acoustic Communication

Ravi Kumar M G[1], Mrinal Sarvagya[2], Navya B R[3]

[1] School of ECE, REVA University, Karnataka, India,
[2] School of ECE, REVA University, Karnataka, India
[3] School of ECE, REVA University, Karnataka, India

Article History: Received: 11 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 23 May 2021

Abstract: Adaptive modulation (AM) technique may make more promote in the execution of wireless communication systems through adaptively conformity transmitter parameters to fading channels; therefore, it has been taken as one of the key physical techniques in underwater acoustic communication. This paper offers a general overview of the adaptive modulation scheme in wireless multiple-input multiple-output (MIMO) systems with Orthogonal Frequency Division Multiplexing (OFDM). Study a set of properties by which adaptive modulation systems are evaluated, and also, discuss modulation schemes, channel modeling and estimation in detail since it is utilized in most current system or solutions, as well survey some MIMO models which are included in adaptive modulation activities in order to enhance the data rate and throughput. In this work, the channel is estimated using Kalman filter. Kalman Filter (KF) is a well-known algorithm for estimation and prediction especially when data has a lot of noise. The EKF is also considered to be the de-facto standard. This paper will provide the idea of MIMO-OFDM receiver design using Adaptive modulation and channel estimation for underwater acoustic communication.

Key words: Underwater communication, OFDM, MIMO, Adaptive modulation, Kalman filter.

1. Introduction

Multiple input multiple output (MIMO) technology is utilized in wireless communications in order to get the better link robustness or to increase the spectral efficiency (SE). The aimed from the Adaptive MIMO transmission will be chosen dynamically for the modulation scheme and the optimum MIMO mode for the purpose of optimizing the spectral efficiency when satisfying the quality of service (QoS) requirements Ref.[1]. Adaptive modulation (AM) systems working to an improved rate of transmission, and/or bit error rates (BERs), through using the channel information that is present at the transmitter. Adaptive modulation systems display great execution enhancements through fading channels compared to systems that do not use the knowledge of the channel at the transmitter. The basic idea of Adaptive Modulation (AM) is to adapt the modulation and coding scheme to the channel state conditions (CSCs) in order to accomplish the highest spectral efficiency at all times. The benefit from using the adaptive modulation (AM) in the wireless systems is to choice of higher order modulation, get the optimum throughput, covering for long distances, and by depending on the channel conditions, it is used to overcome fading and other interferences. Adaptive modulation (AM) may be used to provide many of the parameters which depend to the channel fading, these contain transmit power, channel code rate or scheme, data rate, instantaneous BER, and symbol rate Ref. [2], and Ref. [3].

Adaptive modulation represents promising technical interests to approach the maximum channel capacity in single input -single output (SISO) systems Ref. [4]-[6]. The benefits from Adaptive modulation is to optimize the average spectral efficiency (ASE) depending to the channel state information (CSI) that will be fed back (F.B) from the receiver to the transmitter through adapting transmit parameters, like modulation constellation, transmit power, coding parameters Ref. [7]. The adaptive modulation scheme provides different data rate to different users depending on their channel conditions. With the minimum total transmission power and targeted bit error rate (BER), adaptive modulation scheme assigns the sub-carriers and bits for multi-user in the system based on the time-variant channel information Ref. [8]. AC is one of the adaptive techniques for facing fading and enhances the execution of wireless systems. It used to maximize bandwidth efficiency through chooses an optimal combination from the modulation and coding scheme (MCS), where the resolution is dependent on the channel state information (CSI), so, every MCS will be linked to a coding rate and constellation size Ref. [9]. Thus, Adaptive modulation (AM), is a term utilized in wireless communications to refer to the matching of the modulation and protocol parameters to the average channel conditions for each user (e.g. The path loss, the interference with signals from other transmitters, the usable transmitter power , the sensitivity of the receiver, etc.). Adaptive modulation (AM) enables spectrally efficient transmission through time-varying channels. The basic idea is to estimate the channel at the receiver side and feedback this estimate to the transmitter side, thus, the transmission scheme may be adapted proportional to the channel characteristics [10].

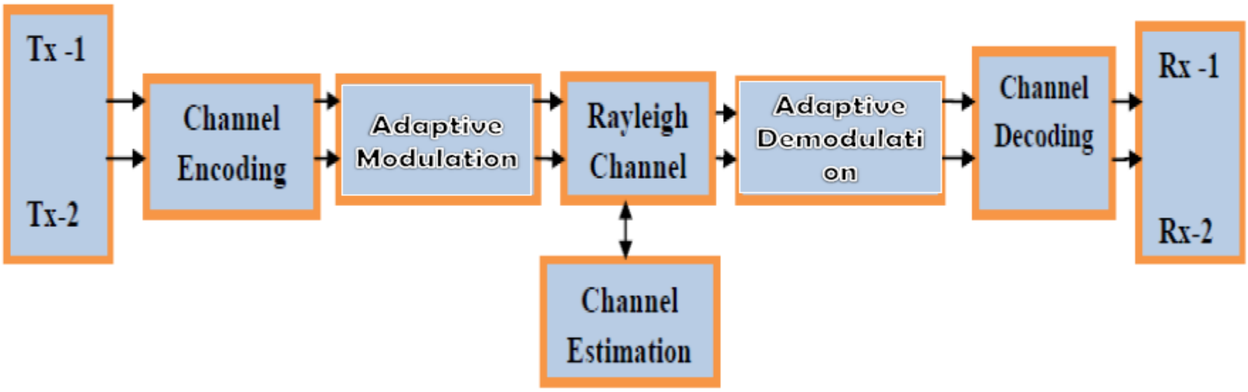
2. Ofdm design and channel modeling

A. Orthogonal frequency division multiplexing(OFDM)

On the subject of the transmission techniques for mitigating the physical limitation of wireless channels caused by multipath fading, dispersion, and interference, a very popular multi-carrier modulation technique which has emerged recently [19]-[20] in the communication field is Orthogonal Frequency Division Multiplexing (OFDM) technique[7]. OFDM is a multi-carrier modulation technique where data symbols modulate a sub-carrier which is taken from orthogonally separated sub-carriers with equal separation within each sub-carrier. This utilizes the bandwidth efficiently as the subcarriers are overlapping and orthogonal to each other. To maintain the Orthogonality, there should be a minimum separation between the sub-carriers to avoid ICI. In practice, discrete Fourier transforms (DFT) and inverse DFT (IDFT) processes are useful for implementing these orthogonal signals. Note that DFT and IDFT can be implemented efficiently by using fast Fourier transform (FFT) and inverse fast Fourier transform (IFFT), respectively.

B. Multiple Input Multiple Output systems (MIMO)

The proposed 2 x 2 MIMO-OFDM is shown in the figure 6.3. In this work we are designing a 2 x 2 MIMO-OFDM which is based on Adaptive modulation, Adaptive channel coding and Channel estimation using Kalman filter for underwater acoustic communication. The methodology is described in detail as follows:



Figure(1). Proposed 2 x 2 MIMO-OFDM system

C. Adaptive Modulation:

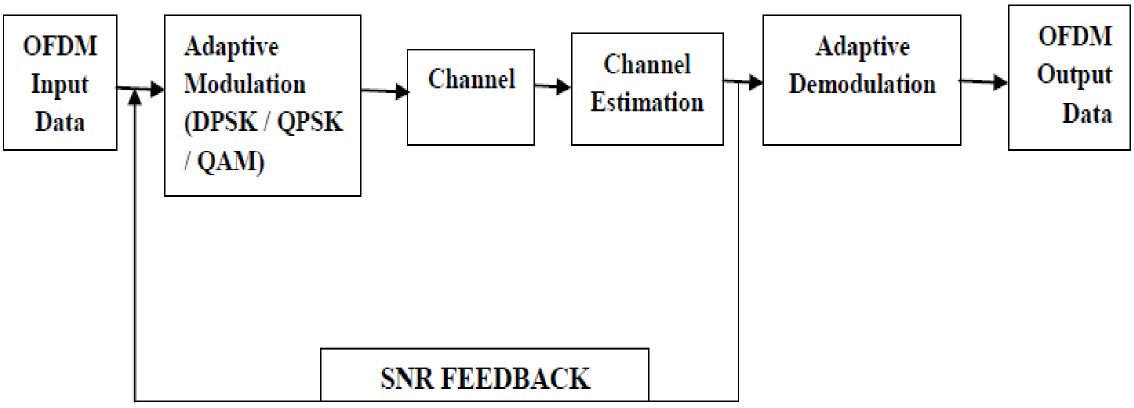
Adapting the transmitter to the channel characteristics has been considered in different forms, including active time-reversal and single-mode excitation. In this work, we establish some efficient modulation schemes such as DPSK, QPSK and 16-QAM for Underwater Acoustic communication in order to enhance the data rate at the OFDM Receiver. We experimented and analyzed individual modulation schemes with OFDM for different channel parameters of Rayleigh channel. Initially we assumed some channel parameters and designed the empirical model by considering the Absorptions coefficient, Transmission loss and the channel noise. Thus we calculated the SNR values initially using the empirical model. Thus we did the OFDM system to switch the appropriate modulation scheme based on the SNR values calculated by the Channel estimation. By applying adaptive technique in the modulation schemes we can enhance the data rate at the MIMO-OFDM receiver. The figure (2) shows the proposed 2x2 MIMO-OFDM architecture.

D. Channel Estimation

Channel estimation is a scheme, in which the channel state information is retrieved by using the channel impulse response. Kalman filtering is an efficient technique to remove impurities in linear systems. The Kalman filter is a recursive predictive filter that is based on the use of state space techniques and recursive algorithms. It estimates the state of dynamic system effectively. In this work we used Extended Kalman filter that is used for nonlinear system, for the channel estimation which leads to increase the data rate by minimizing the mean square error.

3. Methodology

The performance of an adaptive system depends on the transmitter's knowledge of the channel which is provided via feedback from the receiver[7]. Since sound proliferates at an extremely low speed, the structure and execution of a versatile framework basically depends on the capacity to anticipate the channel no less than one travel time ahead. This is an extremely difficult undertaking for correspondences in the scope of a few kilometers which forces huge restrictions on the utilization of feedback[16]. The Proposed Adaptive modulation based OFDM system is shown in the following figure 2.



Figure(2). Proposed Adaptive modulation based OFDM system

A. SNR empirical model

UWA channel offers numerous hurdles to the UWA communication and distorts the signal in many ways, which is likely to be restored by channel estimation and equalization techniques[6][13]. The following are few of the problems being faced specifically by OFDM UWA communication:

1) **Transmission loss**

Transmission loss (TL) is generally occurred because of two parameters: geometric spreading loss and attenuation[33]. For a signal of frequency f_o over a transmission interval d_o, the transmission loss [in dB] can be obtained by

$$10\log TL(d_0, f_0) = k * 10\log(d_0) + d_0 * \alpha(f_0) + A \qquad (1)$$

Where, k= spreading factor

$\alpha(f)$ is the absorption coefficient in dB/m

A=transmission anomaly in dB

f_o = frequency of a signal (kHz)

d_o= transmission distance (m)

2) Acoustic Noise

Due to the shipping activities and machinery noise, the Acoustic Noise will occur usually [1]. The assistance of the key noise sources can be represented by equations (2) to (5) that give PSD's of each noise source with respect to frequency f_o [kHz] in [dB].

$$10\log N_t(f_0) = 17 - 30\log f_0 \qquad (2)$$

$$10\log N_S(F_0) = 40 + 20(S - 5) + 26\log F_0 - 60\log(F_0 + 0.03) \qquad (3)$$

$$10\,LOG\,N_W(F_0) = 50 + 7.5W^{0.5} + 20LOGF_0 - 40LOG(F_0 + 0.4) \qquad (4)$$

$$10\,LOG\,N_{TH}(F_0) = -15 + 20LOGF_0 \qquad (5)$$

Where N_t, N_s, N_w and N_{th} represents turbulence noise, shipping noise, wind noise and thermal noise respectively. For a given frequency f_o the total noise power spectral density is given by

$$N(f_0) = N_t(f_0) + N_s(f_0) + N_w(f_0) + N_{th}(f_0) \qquad (6)$$

3) Attenuation

Attenuation can be generally attributed to absorption[1]. The absorption coefficient can be calculated as

$$\alpha(f_0) = \left(0.002 + 0.11\frac{f_0^{\,2}}{f_0^{\,2}+1} + 0.011 f_0^{\,2}\right) * 10^{-3}$$

(7)

The SNR can be calculated using the transmission loss TL (d_o, f_o) and the noise power spectral density N (f_o) over an interval 'd_o' when the transmitted signal has a frequency of 'f_o' and power 'P_o' is given by

$$SNR(D_0, F_0) = \frac{P/TL(D_0,F_0)}{N(F_0)\Delta(F_0)}$$

(8)

Where $\Delta(f_0)$ indicates the receiver noise bandwidth.

Adapting the transmitter to the channel characteristics has been considered in different forms, including active time-reversal and single-mode excitation.

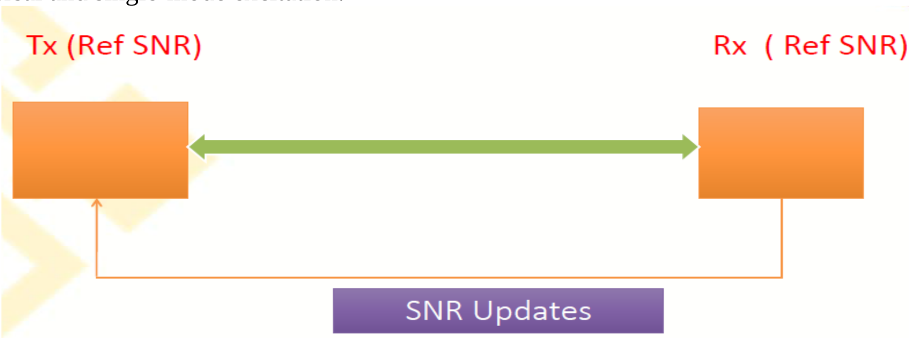


Figure (3). Transceiver with SNR feedback

In this work, we establish some efficient modulation schemes such as DPSK, QPSK and 16-QAM for Underwater Acoustic communication in order to enhance the data rate at the OFDM Receiver. In this work, we experimented and analyzed individual modulation schemes with OFDM for different channel parameters of Rayleigh channel. Initially we assumed some channel parameters and designed the empirical model by considering the parameters like Absorption coefficient, Transmission loss and the channel noise where the channel noise itself consists of Thermal noise, Wind noise, Shift noise and Turbo noise. Thus we calculated the SNR values initially using the empirical model. Then we did the OFDM system to switch the appropriate modulation scheme based on the SNR values calculated by the Channel estimation. By applying adaptive technique in the modulation schemes we can enhance the data rate at the OFDM receiver.

4. Results and discussion

Rayleigh channel (Case-1)

Channel Type : 'Rayleigh'
Input Sample Period : 1.0000e-03
Doppler Spectrum : [1x1 doppler.jakes]
Max Doppler Shift : 0
Path Delays : [0 1.0000e-05 3.5000e-05 1.2000e-04]
Avg Path Gain in dB: [0 -1 -1 -3]
Normalize Path Gains : 1
Store History : 0
Store Path Gains : 0
Path Gains : [-0.4232 + 0.0198i, -0.6846 + 0.3519i, 0.3081 - 0.4653i, -0.3971 - 0.4081i]
Channel Filter Delay : 4
Reset Before Filtering : 1

Figure 4. Raleigh channel parameters for adaptive modulation

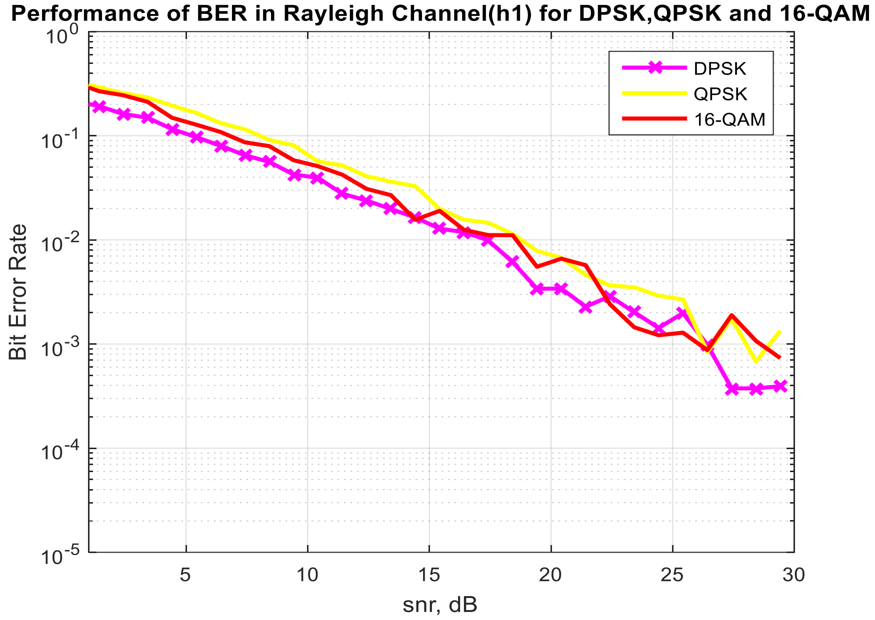
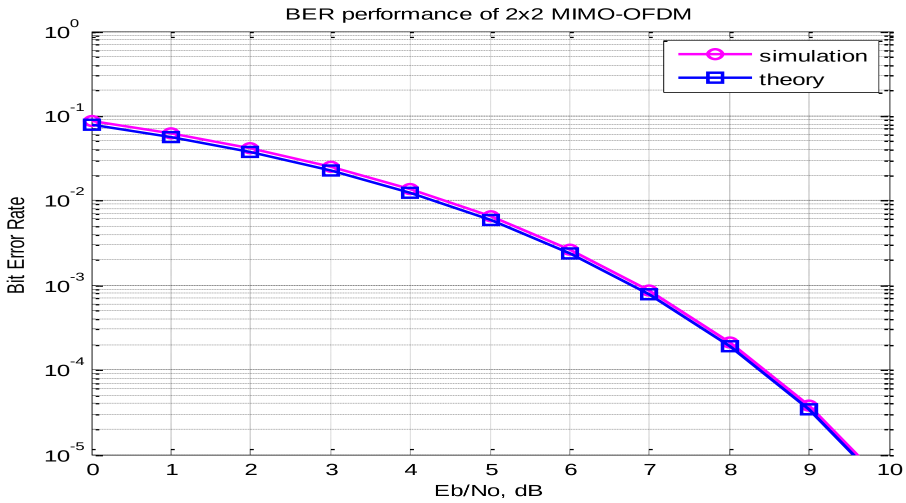


Figure (5). Performance of BER in Rayleigh channel for DPSK, QPSK and 16-QAM

Figure (6). Performance of BER in AWGN channel for 2x2 MIMO-



OFDM

Figure (7). Performance of BER in Rayleigh channel for 2x2 MIMO-OFDM

Table(2). Comparison of BER for different Modulation Techniques and Adaptive modulation (channel estimation):

Modulation Schemes	BER Without Adaptive Modulation and channel estimation	BER With Adaptive Modulation(Channel Estimation)	BER Enhancement (Between With and without Adaptive Modulation and Channel Estimation)
DPSK	0.0008	0.0004	((0.0008-0.0004) / 0.0008)*100 = 50%
QPSK	0.0010	0.0002	80%
16-QAM	0.0013	0.0005	61.5%

Table(6). Comparison of BER performance of 1 x 1 OFDM and 2 x 2 OFDM in AWGN channel and Rayleigh channel:

OFDM system	BER performance with 16-QAM modulation in AWGN channel	BER performance with 16-QAM modulation in Rayleigh channel	BER enhancement between 1x1 OFDM and 2x2 OFDM in Rayleigh channel	BER enhancement between 1x1 OFDM and 2x2 OFDM in AWGN channel
1 x 1 OFDM	0.0007	0.0013	53.8 %	57%
2 x 2 OFDM	0.0003	0.0006		

In this work, we are trying to achieve high data rate using Adaptive modulation based MIMO-OFDM scheme. The SNR is calculated using Empirical model as discussed in section 2. Figure 4 and 5 shows the Rayleigh channel parameters and BER performance using adaptive modulation which includes the modulation techniques DPSK, QPSK and 16-QAM respectively. The performance of BER in AWGN and Rayleigh channel for 2x2 MIMO-OFDM shown in figures 6 and 7 respectively. The BER is 0.0874 in the first iteration but after 8 to 10 iterations the BER goes to zero. The channel estimation is done by using Extended Kalman filter which suits well for the nonlinear system. We also experimented to see the SNR performance of 2x2 MIMO-OFDM systems in AWGN channel. As we know the BER will be very less in AWGN channel compare to Rayleigh channel due to multipath propagation and the simulation results also shown. The BER enhancement between with and without modulation schemes is tabulated in table 2. The Comparison of BER performance of 1 x 1 OFDM and 2 x 2 OFDM in AWGN channel and Rayleigh channel is summarized.

5. Conclusion and future scope

This paper provides a basic idea of the current adaptive modulation techniques and systems for wireless MIMO-OFDM systems. Different execution measurement criteria are discussed and several tradeoffs among them are remarked. In terms of modulation schemes and channel modeling, these adaptive modulation techniques and systems have important characteristics when applied in real conditions. Also discussed the proposed AM for MIMO-OFDM systems that relating to channel characteristics. The channel estimation is done using Extended Kalman filter. Finally, the design 2x 2 MIMO-OFDM for Underwater acoustic communication using Adaptive modulation and Channel estimation is described in detail. In future to improve the data rate and throughput along with Adaptive modulation and Adaptive coding channel estimation can be adapt.

References

1. D. M. Jimenez, G. Gomez, and J. T. Entrambasaguas, “Joint Adaptive Modulation and MIMO Transmission for Non-Ideal OFDMA Cellular Systems,” conference IEEE, 2009.
2. S. T. Chung, and A. J. Goldsmith,” Degrees of freedom in adaptive modulation: A unified view,” IEEE Trans. Commun., vol. 49, no. 9, pp. 1561– 1571, 2001.
3. W. H. Sam, “Adaptive Modulation (QPSK, QAM)”, the Wireless Networking Group, Intel in communications, 2004.
4. M. Dania, T. Daniele, F. Romano, and G. Federico, “ADAPTIVE MODULATION ALGORITHMS BASED
5. ON FINITE STATE MODELING IN WIRELESS OFDMA SYSTEMS”, the 18th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Commun. (PIMRC’07), 2007.
6. F. Romano, M. Dania, T. Daniele, and H. Ibrahim,” Adaptive Modulation and Coding Techniques for OFDMA Systems”, IEEE Trans. Wireless Commun., vol. 8, no. 9, 2009.
7. J. Jing, S. T. John, and S. Hongjian,” A Singular-Value- Based Adaptive Modulation and Cooperation Scheme for Virtual-MIMO Systems”, IEEE Trans. Vehicular Technology, vol. 60, no. 6, 2011.
8. Z. Zhendong, V. Branka, D. Mischa, and L. Yonghui,” MIMO Systems with Adaptive Modulation”, IEEE Trans. Veh. Technol., vol. 54, no. 5, pp. 1828–1842, 2005.
9. J. Shang, Y. Gao, Z. Li, Y. Man, J. Song,” PERFORMANCE STUDY OF ADAPTIVE MODULATION/CODING IN MIMO-OFDM SYSTEM”, Conference on IEEE CCECE, pp. 1559-1562, 2003.
10. H. T. Peng, W. Yan, and S. Sumei,” Link Adaptation Based on Adaptive Modulation and Coding for Multiple- Antenna OFDM System”, IEEE Journal on Communications, Vol. 26, No. 8, pp. 1599-1606, 2008.

11. G. Andrea," WIRELESS COMMUNICATIONS", Stanford University, 2005.
12. S. Y. P. Ada, N. C. T. David, and W. B. Robert," An adaptive multi antenna transceiver for slowly flat fading channels," IEEE Trans. Commun., vol. 51, no. 11, pp. 1820–1827, 2003.
13. N. M. Temme," Special Functions: An Introduction to the Classical Functions of Mathematical Physics", New York: Wiley, 1996.
14. H. Henrik," Adaptive Coded Modulation Performance and Channel Estimation Tools for Flat Fading Channels", Ph.D. dissertation, Norwegian Univ. Sci. Technol., Trondheim, Norway, 2002.
15. H. Bengt," Adaptive Coded Modulation in Spatial and Multiuser Diversity Systems", Ph.D. dissertation, Norwegian Univ. Sci. Technol., Trondheim, Norway, 2005.
16. K. J. Hole, H. Holm, and G. E. Øien," Performance analysis of adaptive coded modulation with antenna diversity and feedback delay," Telektronikk— Information Theory and Its Applications, vol. 98, pp. 106–113, 2002.
17. G. E. Øien, H. Henrik, and J. H. Kjell," Impact of Channel Prediction on Adaptive Coded Modulation Performance in Rayleigh Fading", IEEE Trans. Veh. Technol., vol. 53, no. 3, 2004.
18. H. Bengt, and G. E. Øien," Performance analysis of a rate adaptive dual-branch switched diversity system," IEEE Transactions on Wireless Communications, vol. 56, No.12, 2008.
19. L. Kyunghwan, et al," Throughput improvement of Adaptive Modulation System with optimal Turbo Coded V-BLAST technique using a STD Scheme," 6th International Conference on Information, Communications & Signal Processing, pp. 1-4, 2007.
20. S. Henrik, and L. Christian," Theory and Applications of OFDM and CDMA Wideband Wireless Communications", John Wiley & Sons, Ltd, England, 2005.
21. G. P. John, and S. Masoud," Digital Communications", 5th ed., the McGraw-Hill Companies, Inc., New York, 2008.
22. E. Krouk, and S. Semenov," MODULATION AND CODING TECHNIQUES IN WIRELESS COMMUNICATIONS", Publication in John Wiley & Sons Ltd, 2011.
23. H. T. Peng, W. Yan, and S. Sumei," Link Adaptation Based on Adaptive Modulation and Coding for Multiple- Antenna OFDM System", IEEE Journal on Communications, Vol. 26, No. 8, pp. 1599-1606, 2008.
24. B. Ernst," THE MIMO RADIO CHANNEL", Technische Universität Wien, Vienna, Austria, 2006.
25. B. Aida," MIMO channel models", Msc. thesis, Department of Science and Technology, Universitet Lenkoplngs, 2004.
26. P. Almers, et al," Research Article: Survey of Channel and Radio Propagation Models for Wireless MIMO
27. Systems", Hindawi Publishing Corporation, EURASIP Journal on Wireless Communications and Networking,
28. Article ID 19070, 19 pages, 2007.
29. A CASE STUDY IN USING F.O.G. LEVELED QUESTIONS IN A REMOTE LEARNING ENVIRONMENT, Russell Scott Greene , ChitapaYudthakajkumthorn, Lee Russell Wilkes, International Journal Of Advance Research In Science And Engineering http://www.ijarse.com IJARSE, Volume No. 09, Issue No. 11, November 2020 ISSN-2319-8354(E).
30. P. K. Jean, S. Lauren, I. P. Klaus, E. M. Preben, and F. Frank," A Stochastic MIMO Radio Channel Model With Experimental Validation", IEEE Journal, Selected Areas Commun., vol. 20, no. 6,pp. 1211-1226, 2002.